Portland, Maine
NOISE-CON 2001
2001 October 29-31

MEASURED ENGINE INSTALLATION EFFECTS OF FOUR CIVIL TRANSPORT AIRPLANES

David A. Senzig
Senzig Engineering
7 Everett Street
Boston, MA 02130

Gregg G. Fleming
Volpe National Transportation Systems Center
55 Broadway
Cambridge, MA 02140

Kevin P. Shepherd
NASA Langley Research Center
Hampton, VA 23681-0001

INTRODUCTION

The Federal Aviation Administration's Integrated Noise Model (INM) is one of the primary tools for land use planning around airports [1]. The INM currently calculates airplane noise lateral attenuation using the methods contained in the Society of Automotive Engineer's Aerospace Information Report No. 1751 (SAE AIR 1751) [2]. Researchers have noted that improved lateral attenuation algorithms may improve airplane noise prediction [3]. The authors of SAE AIR 1751 based existing methods on empirical data collected from flight tests using 1960s-technology airplanes with tail-mounted engines. To determine whether the SAE AIR 1751 methods are applicable for predicting the engine installation component of lateral attenuation for airplanes with wing-mounted engines, the National Aeronautics and Space Administration (NASA) sponsored a series of flight tests during September 2000 at their Wallops Flight Facility [4]. Four airplanes, a Boeing 767-400, a Douglas DC-9, a Dassault Falcon 2000, and a Beech KingAir, were flown through a 20 microphone array. The airplanes were flown through the array at various power settings, flap settings, and altitudes to simulate take-off and arrival configurations. This paper presents the preliminary findings of this study.

Figure 1 below shows an example where lateral attenuation influences the received noise. In situation A, the airplane flies directly over the receiver at slant distance R and an elevation angle of 90 degrees. In situation B, the airplane flies at the same slant distance R from the receiver, but at an elevation angle close to zero. Although the slant distances are the same, the receiver at situation B experiences less noise. Two factors contribute to this reduction in noise; the first factor is the influence of the ground on absorbing some of the propagating sound, the second factor is the influence of the airplane geometry itself on shielding some of the noise. This shielding effect is referred to as “engine installation effects.” This study examined how specific airplane geometry influences engine installation effects. The specific airplane geometries examined were wing-mounted engines and tail-mounted engines.

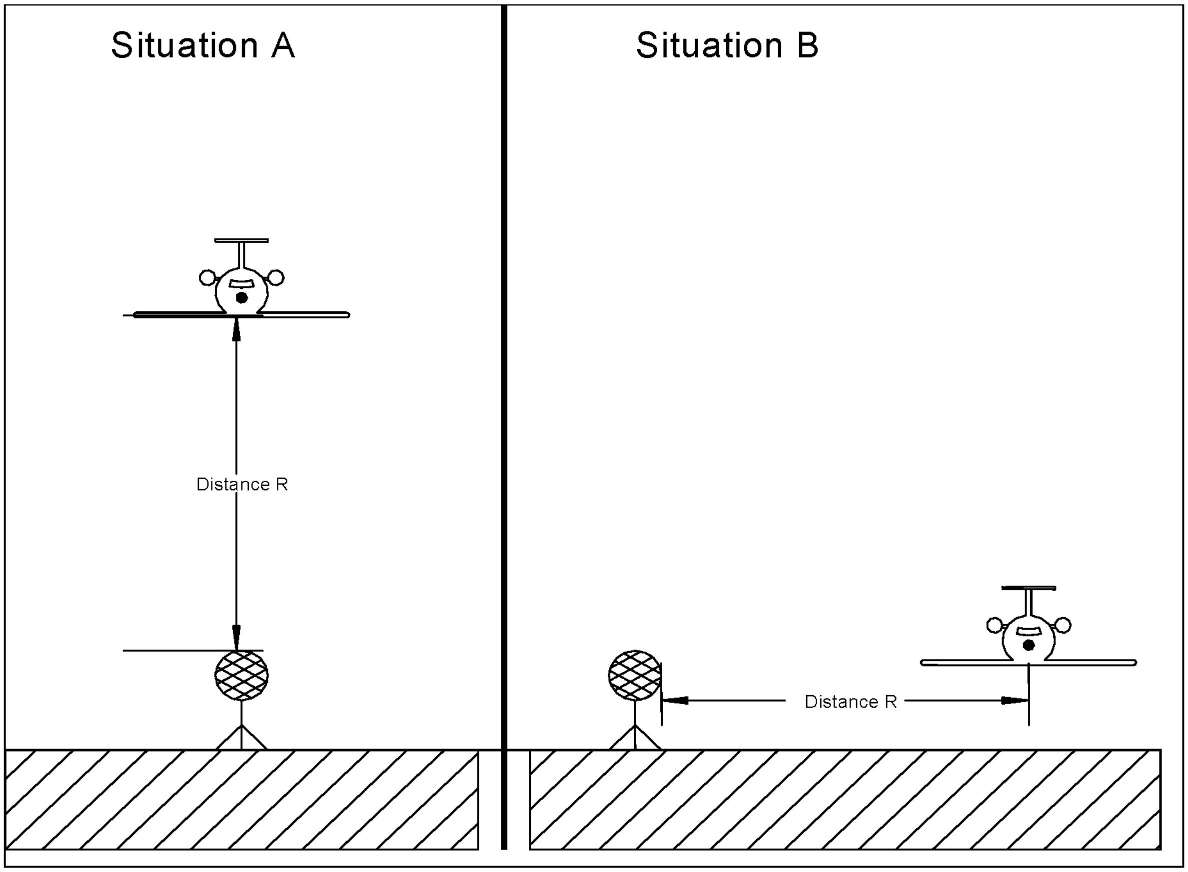

Figure 1: Lateral Attenuation schematic

EXPERIMENTAL METHOD

Flight tests were conducted from September 16 to 28, 2000 at the National Aeronautics and Space Administration's (NASA) Wallops Flight Facility (WFF). Twenty microphones were aligned perpendicular to WFF's east-west runway. Of these twenty microphones, ten were suspended from two 200 foot cranes 485 feet from the runway centerline, nine were mounted on 24 foot poles, and one was placed on the surface of the runway at the centerline. The ten suspended microphones were mounted on a flexible aluminum ladder structure; this aluminum ladder was stabilized with guy wires to prevent any rotation of the microphones. The nine pole-mounted microphones were high enough so that any interference between the direct acoustic path and the reflected acoustic path would occur at frequencies lower than the normal range of interest. Figure 2 below shows a schematic of the microphone and airplane positions.

The four test airplanes were flown through this microphone arrangement. Each airplane was flown at four different power settings. These settings corresponded to a full power takeoff, a reduced power takeoff, cruise power with approach flaps, and cruise power with minimal flaps. Flaps were required with cruise settings because the airplanes were flown at approximately the same speed for all passes. Six passes at each power setting were performed; five passes were made over the centerline of the runway, one pass was made 100 feet off centerline. The centerline passes were made at 400 feet (twice), 240 feet (once), and 200 feet (twice)

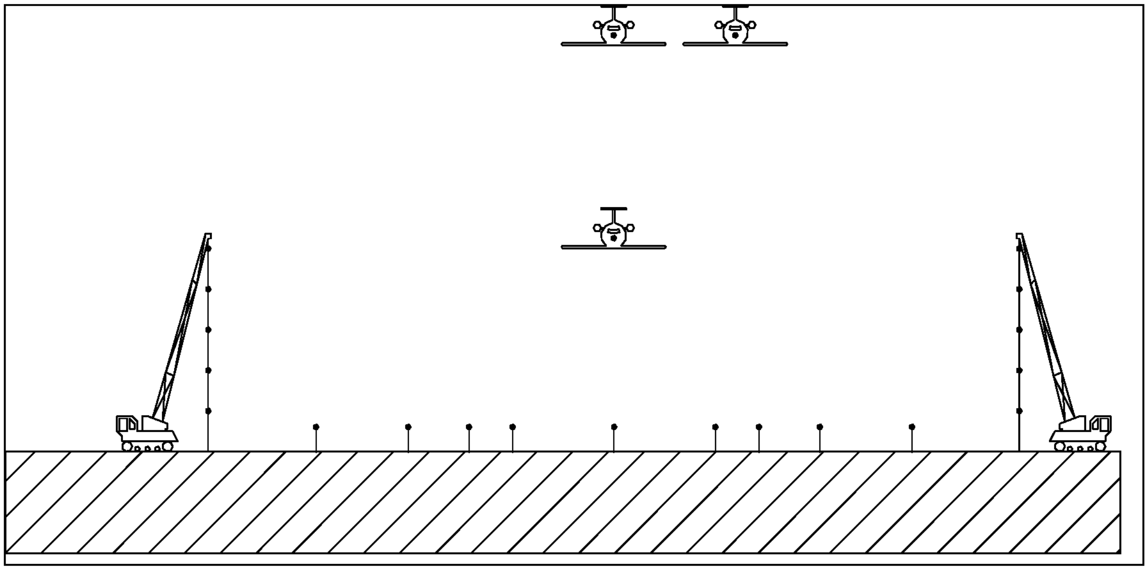

Figure 2: Microphone and airplane position schematic

above ground level (AGL). The 240 foot AGL pass is not represented in Figure 2. The off-centerline passes were made at 400 feet AGL. This combination of microphone locations and airplane pass altitudes and offsets gave a full range of elevation angles for each power setting.

Acoustic data were acquired on each pass from approximately 40 seconds before the airplanes passed through the array until approximately 20 seconds after. The airplanes were tracked with either onboard differential GPS or a video tracking system. Power settings were recorded by the flight crews and relayed to the test staff after each pass.

DATA REDUCTION

The one-third octave acoustic data were combined with the tracking data to yield the Sound Exposure Level (SEL) and the A-weighted sound level at the Closest Point of Approach (L_{cpa}). These metrics were calculated after correcting for spherical spreading, atmospheric absorption, duration effects (SEL only), and ground effects. The L_{cpa} metric was used to compare the results of this study with those of a previous long-range over-water propagation study [5]. The SEL and L_{cpa} values for each microphone were compared to the reference microphone for the particular pass. All centerline passes used microphone 11, the centerline microphone, as the reference microphone. The off-center passes used the microphone with the highest elevation angle at CPA as the reference microphone; this was either microphone 11, 12, or 13.

Data that were noted as contaminated at the time of the flight test were removed from the analysis. Generally this removed data for individual microphones. Only two complete passes were dropped from the analysis; in one pass, the video tracking equipment did not function correctly, in the other pass, unexplained tones were noted in the acoustic data from the microphones on one side of the airplane, but not on the other.

RESULTS

The results of analyzing the data for two of the four airplanes are shown below in Figures 3 and 4. In addition to the engine installation effect plotted as a function of elevation angle, the figures also show the plotted SAE AIR 1751 algorithm. For the 767, an airplane with wing-mounted engines, engine installation effects appear below an elevation angle of about 30 degrees. For the

DC-9, an airplane with tail-mounted engines, engine installation effects appear below about 60 degrees. For both airplanes, the trend is less effect than that predicted by SAE AIR 1751, but this comparison is somewhat misleading since SAE AIR 1751 includes grounds effects that have been removed from this study. For the DC-9, the trend is for general agreement with SAE AIR 1751 above about 35 to 40 degrees. The better agreement between DC-9 and SAE AIR 1751 is not surprising, given that SAE AIR 1751 was originally developed from flight tests with a Boeing 727 airplane, which have 3 co-planar fuselage-mounted engines. Figure 5 shows the data for the Dassault Falcon 2000 resemble that of the DC-9. The KingAir data, Figure 6, showed no discernible engine installation effects. For comparison with the airplane type used to develop SAE AIR 1751, Figure 7 shows engine installation effects for 727 airplanes measured during normal operations at Logan Airport in Boston during an earlier measurement program [5]. Note that the original data from the Logan study as presented in Reference 5 were re-processed in support of this study to calculate the SEL metric.

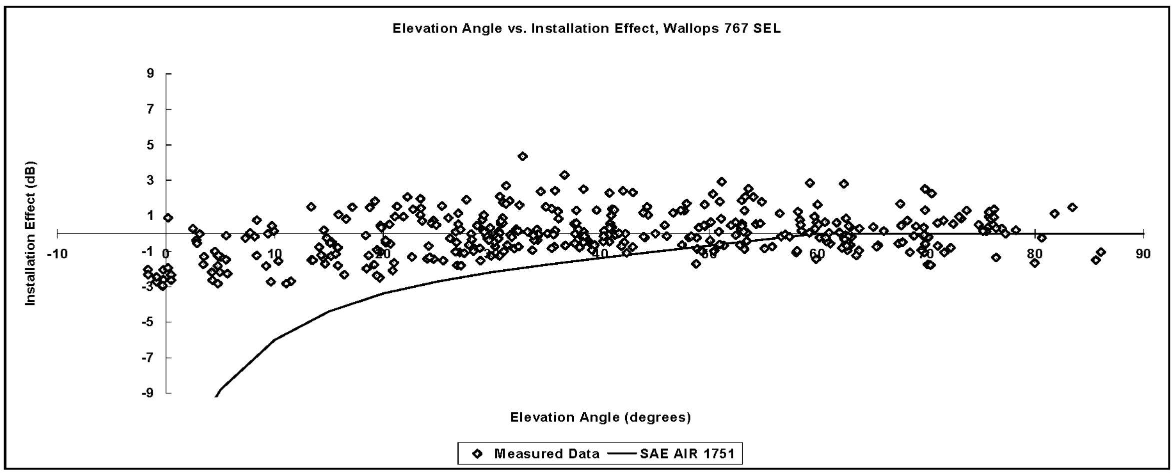

Figure 3: 767 Engine Installation effects, all passes

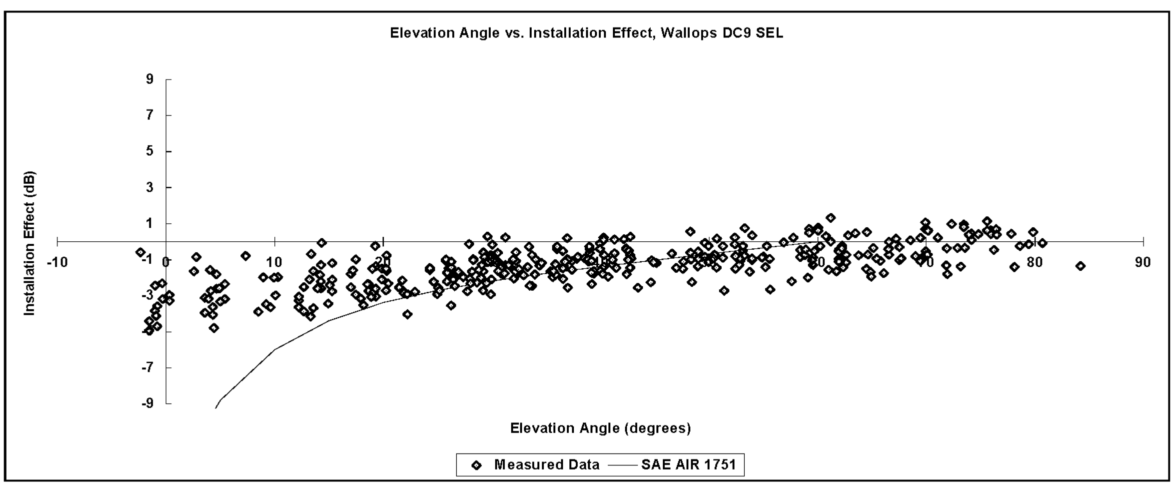

Figure 4: DC-9 Engine Installation effects, all passes

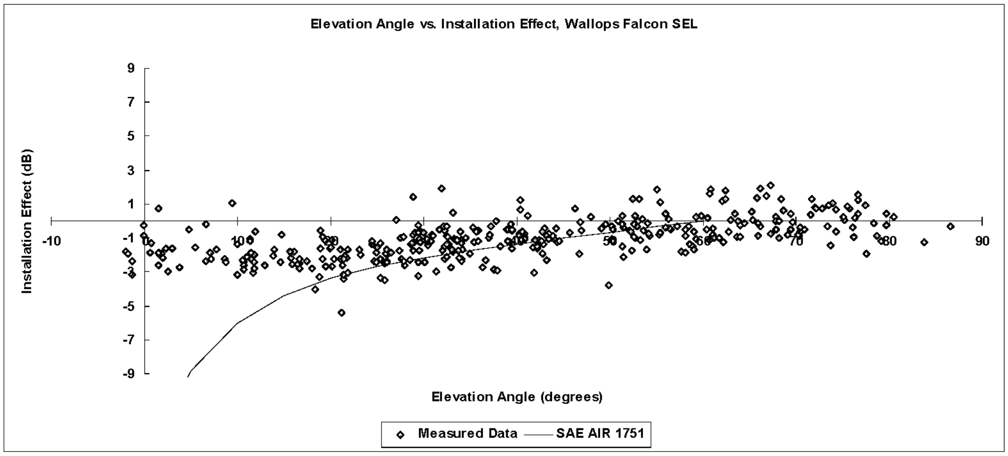

Figure 5: Dassault Falcon 2000 Engine Installation effects, all passes

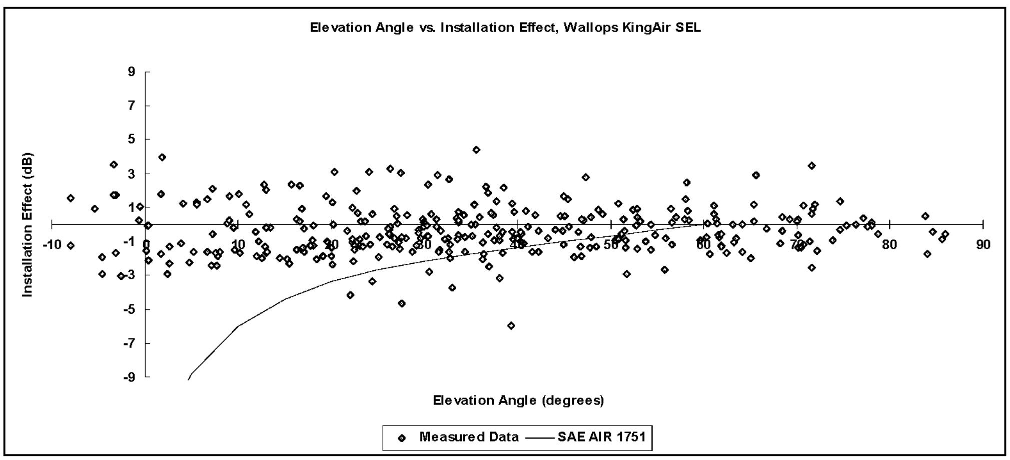

Figure 6: Beech KingAir Engine Installation effects, all passes

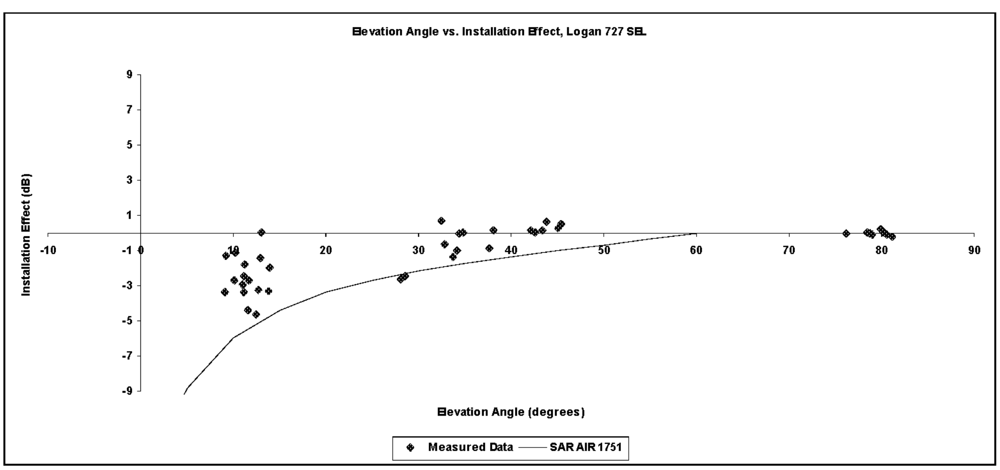

Figure 5: 727 Engine Installation effects, measured at Logan Airport

CONCLUSIONS AND ADDITIONAL WORK

The data appear to support dividing the engine installation component of a new lateral attenuation algorithm into at least two equations, one for airplanes with wing-mounted engines, the other for airplanes with tail-mounted engines. Based on the limited data collected at WWF, propeller airplanes appear not to have a significant engine installation effect.

Any new engine installation equations should be combined with the SAE aircraft noise sub-committee's ongoing work on ground effects to produce a comprehensive lateral attenuation suite. However, before that can be done, additional analysis of the data collected at WFF is required to determine if power and flap setting for the various airplane geometries also influence engine installation effects.

REFERENCES

1 "INM Technical Manual," FAA AEE-97-04 (December 1997)

2 "Prediction Method for Lateral Attenuation of Airplane Noise During Takeoff and Landing," SAE No. 1751 (March 1981)

3 "Validation of Aircraft Noise Prediction Models at Low Levels of Exposure," NASA CR-2000-210112 (April 2000)

4 "A Controlled Study to Examine the Lateral Attenuation of Aircraft Sound Levels: Wallops Study," Volpe National Transportation Systems Center, DTS-34-VX005-LR2 (August 2000)

5 "Lateral Attenuation of Aircraft Sound Levels Over an Acoustically Hard Water Surface: Logan Airport Study," NASA CR-2000-210127 (May 2000)